A Game-Based Approach for Hemiplegia Lower Limb Rehabilitation

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***Abstract*—Hemiplegia is paralysis which occurs on one half of the body. Rehabilitation for hemiplegic patients, in order to prevent muscle degeneration from prolonged under-usage, can be boring as it requires the same movements to be performed repeatedly. This research project aims to reduce the cost of rehabilitation for hemiplegia patients by demonstrating an exoskeleton with the implementation of only a single active actuator as opposed to other complex designs with multiple active actuators. Moreover, the proposed game-based exercises can motivate and minimize boredom of patients in lengthy and intensive therapy sessions. This paper presents the design, control and preliminary evaluation on the feasibility of a low-cost rehabilitation approach that can be implemented for both home based therapy or rehabilitation center therapy. The proposed approach demonstrates a lower extremity exoskeleton with the implementation of only one DC motor located at the hip, in which it is linked to a video game, and is monitored and controlled by an ATmega328 microcontroller based on commands from the video game. Preliminary result shows that the movement of the exoskeleton can be controlled through commands from the video game but with a delay of 2s.**

Keywords—exoskeleton, robot-assisted training, lower extremity, game therapy, hemiplegia, paralysis, rehabilitation

I. INTRODUCTION

Hemiplegia is defined as a type of neuromuscular disorder whereby only half of the body is paralyzed while the other half is able to function normally [1]. The prevalence of Spinal Cord Injury (SCI) patients lies in between 10.4 and 83 per million inhabitants per year worldwide, with two-third of SCI patients being paraplegic [2]. Muscles on the involved side of paralysis will begin to degenerate if they are not being used or flexed [1]. Besides that, complications such as pressure ulcers, will also arise due to the building up of pressure under the skin when not moving for some period of time [3]. Most patients with hemiplegia can be rehabilitated, with the exception of patients with the following conditions: senility, psychosis, medical complications which prohibits rehabilitation, loss of learning ability, lack of motivation, and atonicity [4].

Rehabilitation, which is described as the combination and coordination of medical, educational, social and vocational embedded into individual training for the attainment of highest possible functional ability, takes many different forms, which includes physical therapy, occupational therapy, speech-language therapy and treatment of pain [5]. In order for the rehabilitation to be effective, physical therapy must be intense with repetitive practice of the same movement and actions [6]. Traditionally, therapies focus more towards treadmill training in order to improve the mobility of patients. However, for manually assisted treadmill training, sometimes there is a need of more than three therapists to assist the leg movements of a patient [7]. On top of that, in order to ensure correct gait patterns to be produced, physical constraints and bad positions encountered by the therapists will result in the therapists suffering from back pains [8]. Thus, in order to enlighten therapists from heavy work during rehabilitation, and to help hemiplegic patients to regain the ability to move, assistive devices such as exoskeletons are being developed and used in therapy.

Exoskeletons used in physical therapy can be categorised based on its function, which includes, treadmill gait trainers, foot-plate-based gait trainers, overground gait trainers, stationary gait trainers and ankle rehabilitation systems [7]. Treadmill gait trainers includes Lokomat [9], LOPES [10] and ALEX [11]. Foot-plate-based gait trainers functions by positioning the patient's feet on separate foot plates and different gait patterns are simulated by the robotic system – HapticWalker [12], GaitMaster5 [13]; whereas overground gait trainer follows the patients motion rather than moving the patients through a predetermined set of patterns – HAL [14], ReWalk [15]. Besides that, stationary gait trainers – MotionMaker [16], Lambda [17]; and ankle rehabilitation systems – MIT-AAFO [18], Rutgers Ankle [19]; functions to guide the movement of limbs and to restore ankle motions respectively.

Despite the advancement in the technology of exoskeletons, it is well established that task-specific practice is required for the relearning of locomotor skills [20]. And hence, the repetition of the same movement will cause boredom and fatigue to both the patient and therapist [21]. In addition, repeated exposure to motor activity, without usefulness or meaning in terms of function, is not sufficient to induce functional recognition and representational plasticity in cortical motor maps [22, 23].

On top of that, many studies have also shown that playing video games will help improve physical and cognitive abilities such as reaction time, attention and memory of patients and can improve patients' motivation in undergoing therapy [24-26]. Nowadays, researchers have developed software game console based therapy system – Nintendo Wii [27], Sony PlayStation [28], Microsoft Kinect [29]; and systems designed specifically for paralyzed patients of the upper extremity – TheraJoy [30], T-WREX [31], RUPERT [32]. However, these systems require the patients to be able to have slight hand movements or to put on an exoskeleton; and some are also too expensive or complex to be used [26].

In this work, a low cost robot-assisted lower limb exoskeleton, following the concept of stationary gait trainers, was proposed. This rehabilitation system implements task-oriented training, in which the same movements are performed repeatedly, to increase the effectiveness of therapy. Moreover, to improve the patient's motivation, the exoskeleton is directly linked to a 2D visual gaming therapy, in which the motion of the exoskeleton is determined and controlled by commands from the video game.

II. Design

The aim of this work is to develop a research prototype that can aid in the movement of a single joint, which is a repetitive training of an isolated movement as opposed to treadmill training. A research in [33], which involved 27 hemiplegic patients, shows that frequent and repetitive movements is able to improve specific movement parameters of the hand as compared to standardized training of hand and finger movements in conventional physiotherapeutic methods. Hence, with only a single active actuator, as opposed to other complex designs such as ReWalk which consists of two active and one passive actuators and priced at RM300,000 [34], the complexity of this proposed exoskeleton is greatly reduced, which subsequently reduces the cost of fabrication and maintenance.

A. Degree of Freedom (DOF)

Since this exoskeleton is used to perform task-oriented repetitive movement, the robot only needs one active DOF movement in the sagittal plane, which is hip flexion/extension (Fig. 1). The upper limb and lower limb is linked at the knee whereby it is mechanically locked at a desired position to avoid the swinging of the lower limb when the upper limb is in motion. Besides, by locking the knee joint at different angles, the difficulty of the exercise can be altered, in which results from [35] shows that different knee flexion will affect the maximum torque in hip flexion/extension.

B. Actuator and Sensor

In order to save cost and reduce the complexity of the exoskeleton, the actuator must have good position controllability, not back-drivable, have high torque to weight ratio and is reliable [36]. Hence, we proposed a DC Motor as an active actuator. By implementing gear drive, the torque can be increased by reducing the speed using gear reduction. In this work, a Geared DC Motor with gear ratio of 270:1 was used. Magnetic quadrature encoder is fitted on the rear shaft of the motor to sense its angle of rotation. Since the encoder provides 3 counts per revolution of the rear shaft, 810 counts are produced per main shaft revolution.

C. Video Game

A video game was developed for the rehabilitation of the lower extremity, in which ten muscles are targeted as shown in Fig. 2. The game was written using C language with the implementation of SwinGame Application Programming Interface (API), and the usage of MinGW (Minimalist GNU for Windows) compiler with its supplement MSYS (Minimal System) command shell.

Based on game design principles obtained from [37] of giving immediate feedback and increasing the challenge of the game, the game was designed according to the flow chart as shown in Fig. 4. Four game objects will be displayed randomly on the screen as shown in Fig. 3, in which player presses the matching button on the keyboard within the required time to make the character move. A match will result in an increase in Score, which also serves as the continuity factor. As the game advances, the game becomes more challenging when the arrows are displayed at a faster pace. The ultimate aim is to beat the high-score. In [38], it shows that the motivation to beat a high-score is an effective strategy in increasing user participation, in which it encourages comparison and competition.

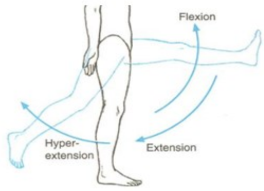

Fig. 1. Hip flexion/extension movements [39]

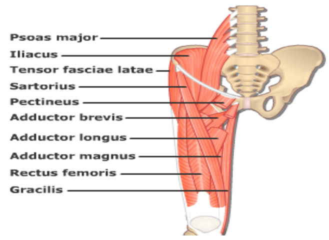

Fig. 2. Targetted muscles of hip flexion/extension movements [40]

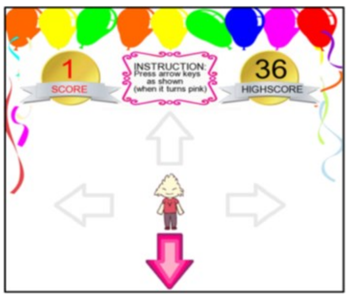

Fig. 3. Graphical User Interface (GUI) for the game based system

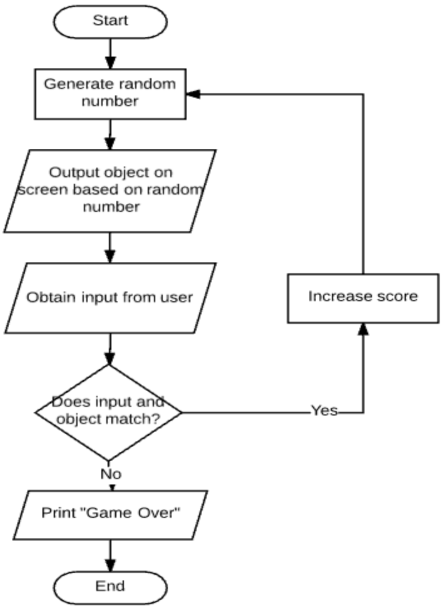

Fig. 4. Flow chart of the video game

D. *Data Logging*

Data are obtained from the video game as well as the sensor (Fig. 5). Hence, different types of data are stored in different formats to be processed differently.

1) Data Storage 1

This is a text (.txt) file outputted by the C program as shown in Fig. 6. This file is responsible for keeping track of all the scores for every game using ID number in order to generate the high score. Data inside this file will be processed by the C program by looping through the entire file through comparison of ID number, in which it will return the highest value stored inside this file.

2) Data Storage 2

This is a comma separated values (.csv) file, in which commands are only generated when the arrows are pointing up and down as shown in Fig. 7. The data inside this storage file, which serves as commands to the exoskeleton, will be processed by the Arduino through Processing IDE in order to generate motions for the exoskeleton. The serial library of Processing is used to read data one byte at a time from the csv file, whereby only new values are sent to the Arduino. When it reaches the end of the file, Processing will check from the file for new values every 0.5 seconds.

3) Data Storage 3

This file is used to store the rotational movements measured by the sensor. Time-stamps and dates are added to this file with the aid of a real-time clock (RTC) module. This csv file (Fig. 8) is outputted by the Arduino using Processing IDE, and is imported into Microsoft Excel or MATLAB to form a table with values entered into different rows and columns. Graph of angle against time can then be plotted using the software to observe the rotational movement of the patient.

E. *Control*

Fig. 5 shows the block diagram for the closed-loop control system. The control strategy implemented is based on signals collected from the exoskeleton only. The advantage of this control strategy is that the prediction of the wearer's intention of motion is not required; hence a simpler interface is required to estimate and follow the wearer's intention based on the signals collected from only the exoskeletons. This system, as shown in Fig. 5, implements position controller by specifying a precise joint angle trajectory of repetitive isolated movements, in which the patient will be using a wireless keyboard as a remote control to give input into the game. The commands required to move the exoskeleton will be stored in Data Storage 2, which is then read by the Arduino through Processing. The Arduino, together with the magnetic quadrature encoder which provides feedback into the Arduino, will be responsible to move the exoskeleton to its desired angle. Movements of the exoskeleton will be stored inside Data Storage 3 for the monitoring and evaluation by the therapist.

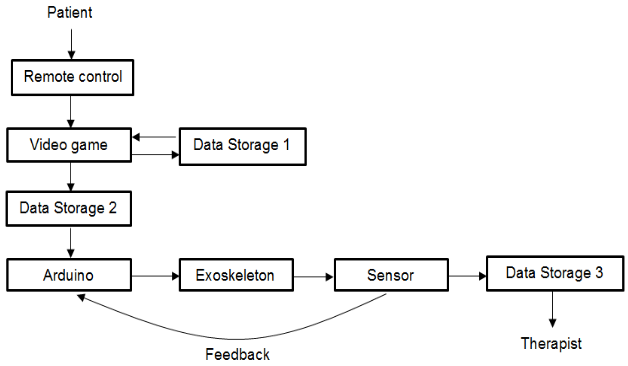

Fig. 5. Proposed framework for exoskeleton system

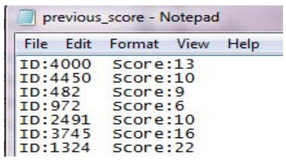

Fig. 6. Format used in Data Storage 1

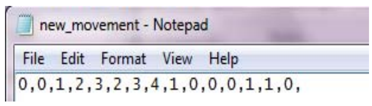

Fig. 7. Format used in Data Storage 2

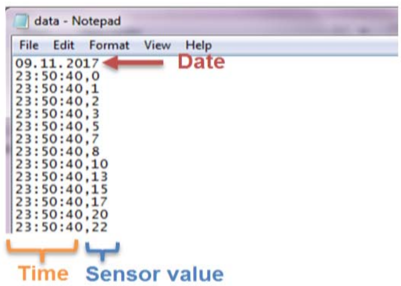

Fig. 8. Format used in Data Storage 3

F. *Exoskeleton Prototype*

For a small-scale testing on the feasibility of controlling the movement of the exoskeleton through commands from the video game, the control system was tested on a single actuated prototype of exoskeleton as shown in the experimental setup as shown in Fig. 9. The prototype, which was constructed using paper rolls, stainless steel, Velcro tap, H-bridge and a geared DC motor, was produced for this small-scale testing before the implementation of this control system onto the actual model which will be constructed in the future. Fig. 10 shows the closed loop control system in which the direction and angle of rotation of the DC motor is controlled by the H-bridge and encoder respectively.

III. Evaluation of Control System

The overall control system is mainly evaluated based on the ability of the exoskeleton to move according to the commands of the game. Before the overall testing of the system is done, separate testing of different sections is carried out to ensure that each individual section can function independently, which are the video game, Processing and Arduino.

Since the game will be generating arrows randomly, different motions of the exoskeleton poses a challenge to produce repeated results to obtain its average. Hence, the game was programmed to generate four "up" arrows just for the purpose of obtaining required measurements. Besides, testing was also done on the motor with increasing load in increments of 44g. The load was attached to the middle section of the internal side of the prototype to ensure that both limbs have the same centre of mass. All results were obtained from the output of the encoder which is stored in Data Storage 3, in which the csv file was opened in Microsoft Excel. The rows and columns containing the data were selected to produce line graphs.

IV. Preliminary Results

Preliminary results of this system in Fig. 11 show that measured result lags the expected result by approximately 2 seconds. The expected angle of rotation of the exoskeleton was calculated using the rpm of the motor, and was plotted in blue dotted lines together with the measured results. This delay is caused by the game, whereby the comparison of input from users with the arrows displayed on the screen is only done after the arrows are removed from the screen. Although the system was designed not to have any delays between the game and the motion of exoskeleton, this delay of 2s will not directly affect the patient because the patient has no sensation of the movements. However, this limitation can be countered by changing the design of the game in the future.

Result in Fig. 12 shows that when the load is increased, the time taken to reach its desired angle also increased. This is because when the mass increases, the torque also increases, which will subsequently decrease its speed. Besides, Table I shows the calculation that for every increase in 1g, the expected increase in time will be 1.52s. From this, the time to reach a certain angle can be predicted based on the mass of the exoskeleton, provided that the torque limit is not violated.

V. Conclusion and Future Work

This paper highlights the initial study on the development of low-cost rehabilitation approach using a game based system. Overall, results show that despite the delay between the game and motion of exoskeleton, the movement of the exoskeleton can be controlled by commands from the video game and has the potential for further investigation. Since it only implements a single active actuator as compared to other complex multi-actuated exoskeletons in the market, its complexity and cost are greatly reduced, which makes it suitable for both home based therapy or rehabilitation center therapy. In the near future, we will develop the actual model of this exoskeleton and implement it to the gaming system proposed, and evaluate its functionality using healthy test subjects with the addition of EMG sensors to monitor muscle activities.

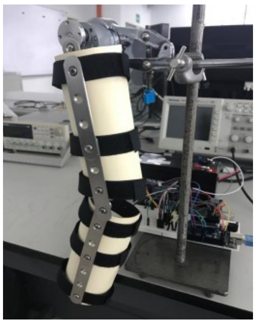

Fig. 9. Experimental setup of prototype of exoskeleton

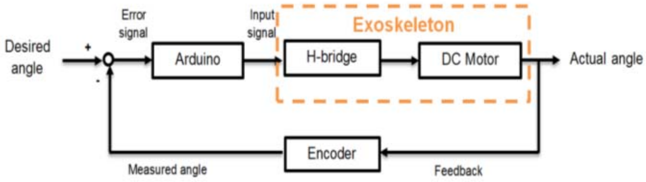

Fig. 10. Closed loop control system

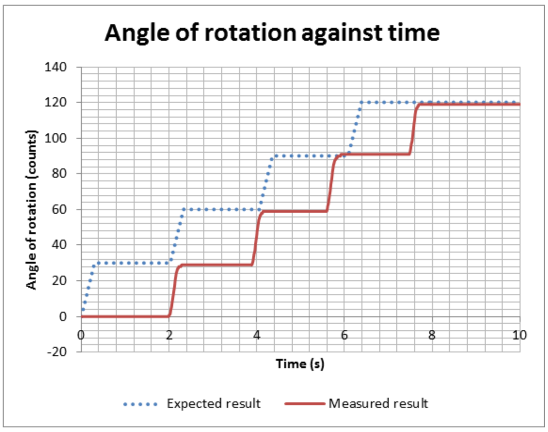

Fig. 11. Expected angle of rotation of motor versus measured angle subjected to load

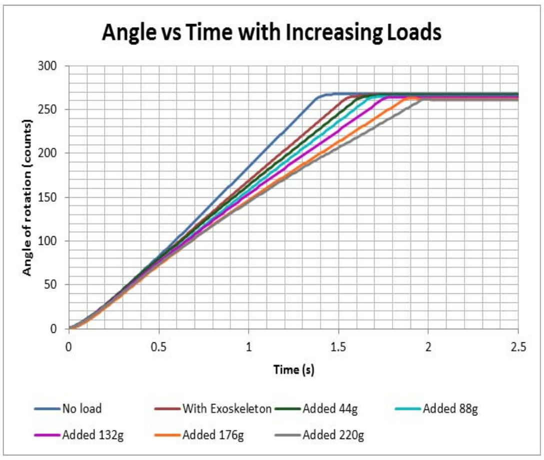

Fig. 12. Angle of rotation of the motor with increasing loads

TABLE I. CALCULATION OF INCREMENT OF TIME WITH WEIGHT

	Total weight (g)	Time to reach angle (s)	Time difference (s)	Time increment (ms/g)
No load	0	1.43	-	-
Exoskeleton	184	1.6159	0.1859	1.01
Added 44g	228	1.6874	0.0715	1.625
Added 88g	272	1.758	0.0706	1.605
Added 132g	316	1.8304	0.0724	1.645
Added 176g	360	1.9019	0.0711	1.616
Added 220g	404	1.973	0.0711	1.616
			Average:	1.52

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